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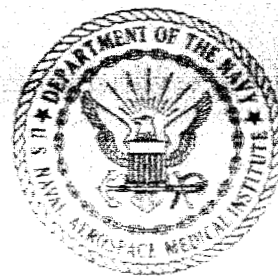
THE ELECTROENCEPHALOGRAM OF THE SQUIRREL MONKEY (Scimiri sciureus)

IN A VERY HIGH MAGNETIC FIELD

Dietrich E. Beischer and James C. Knepton, Jr.



JOINT REPORT



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THE ELECTROENCEPHALOGRAM OF THE SQUIRREL MONKEY (Saimiri sciureus)  
IN A VERY HIGH MAGNETIC FIELD\*

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## SUMMARY PAGE

### THE PROBLEM

Electromagnetic propulsion systems, shielding, and other onboard magnetic devices may expose astronauts for prolonged periods of time to strong magnetic fields. Experiments with sublimis primates are necessary in preparation for systematic investigation of possible effects of such fields on man. A study of the electrical activity of the cerebrum in a strong magnetic field is of special interest.

### FINDINGS

In preparation for an appraisal of the possible effect of strong magnetic fields on cerebral functions electroencephalograms of squirrel monkeys subjected to strong homogeneous and gradient fields (up to 91,250 oersted) were measured. Higher than normal amplitudes and frequencies were found in the recordings from exposed animals. The unusual EEG records are discussed and an attempt is made to explain the observation. The study is part of a plan to investigate interaction of magnetic fields with the nervous system in general.

### ACKNOWLEDGMENTS

Grateful acknowledgment is made to the staffs of the Cryogenics Branch, Solid State Division, U. S. Naval Research Laboratory, Washington, D. C., and the National Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts. In particular, the assistance and cooperation of Mr. J. Reid Clement, NRL, and Mr. Lawrence Rubin, NML, have contributed to the success of these experiments.

Experiments reported herein were conducted according to the principles enunciated in "Guide for Laboratory Animal Facilities and Care" prepared by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences-National Research Council.

## INTRODUCTION

The application of high magnetic fields is being considered for future space travel in a number of respects (1). Since astronauts may become exposed to such fields for prolonged periods of time, studies of the effects on nonhuman primates seem essential. A study of the influence of magnetic fields on electrical phenomena in living organisms promised to be particularly rewarding after significant changes of the electrocardiogram were observed in strong magnetic fields (2). This report demonstrates that the electroencephalogram (EEG) of squirrel monkeys is also subject to changes by high magnetic fields: Higher than normal frequencies and amplitudes were observed in the EEG of animals exposed to strong fields, as high as 91,250 oersted.

## PROCEDURE

Two types of magnets built according to the Bitter principle were used, one located at the U. S. Naval Research Laboratory (NRL), Washington, D. C., and the other at the National Magnet Laboratory (NML), Massachusetts Institute of Technology, Cambridge, Massachusetts (Figure 1). Both magnets with vertical cores four inches in diameter can be operated for prolonged periods of time at high field strengths.

A total of nine squirrel monkeys (*Saimiri sciureus*), 4 females and 5 males (316 to 560 grams), were used in three separate series of experiments. The animals had been kept in the colony at Pensacola for some time prior to the experiments under the supervision of a veterinarian. The monkeys were prepared to tolerate restraint by systematically increased periods of immobilization applied for several weeks before the exposure to magnetic fields. During the experiment an animal was placed with its back on a fitted, half-cylindrical couch and restrained by Velcro (American Velcro, Inc.) fasteners (Figure 2). The couch with the animal was inserted into a nonmagnetic cylinder which fitted into the core of the magnet.

For measurement of the electroencephalogram during the last two series of the experiments five silver needle electrodes were inserted just through the scalp on the left side in the frontal (F), parietal (P), temporal (T), occipital (O), and median (ground) cranial regions. Six channels (F-P, P-O, F-T, O-T, P-T, F-O) of bipolar EEG recordings were registered. The first series of experiments was conducted with only the P, O, and ground leads. Various amplifier and recording systems were utilized: in the first set of experiments a Taber Instrument Corporation Model 228 amplifier and a Sanborn Model 51 recorder; in the second series of experiments, Sanborn 350-2700 amplifiers, a Sanborn 350 paper recorder, and a Sanborn 2000 tape recorder; and in the third series, an Offner Electronics Incorporated Type T electroencephalograph. The amplifiers were connected by shielded, nonmagnetic wires to the electrodes, and tracings were obtained several weeks and immediately before, as well as during and after the exposure to magnetic fields. All amplifier inputs are of the differential kind.

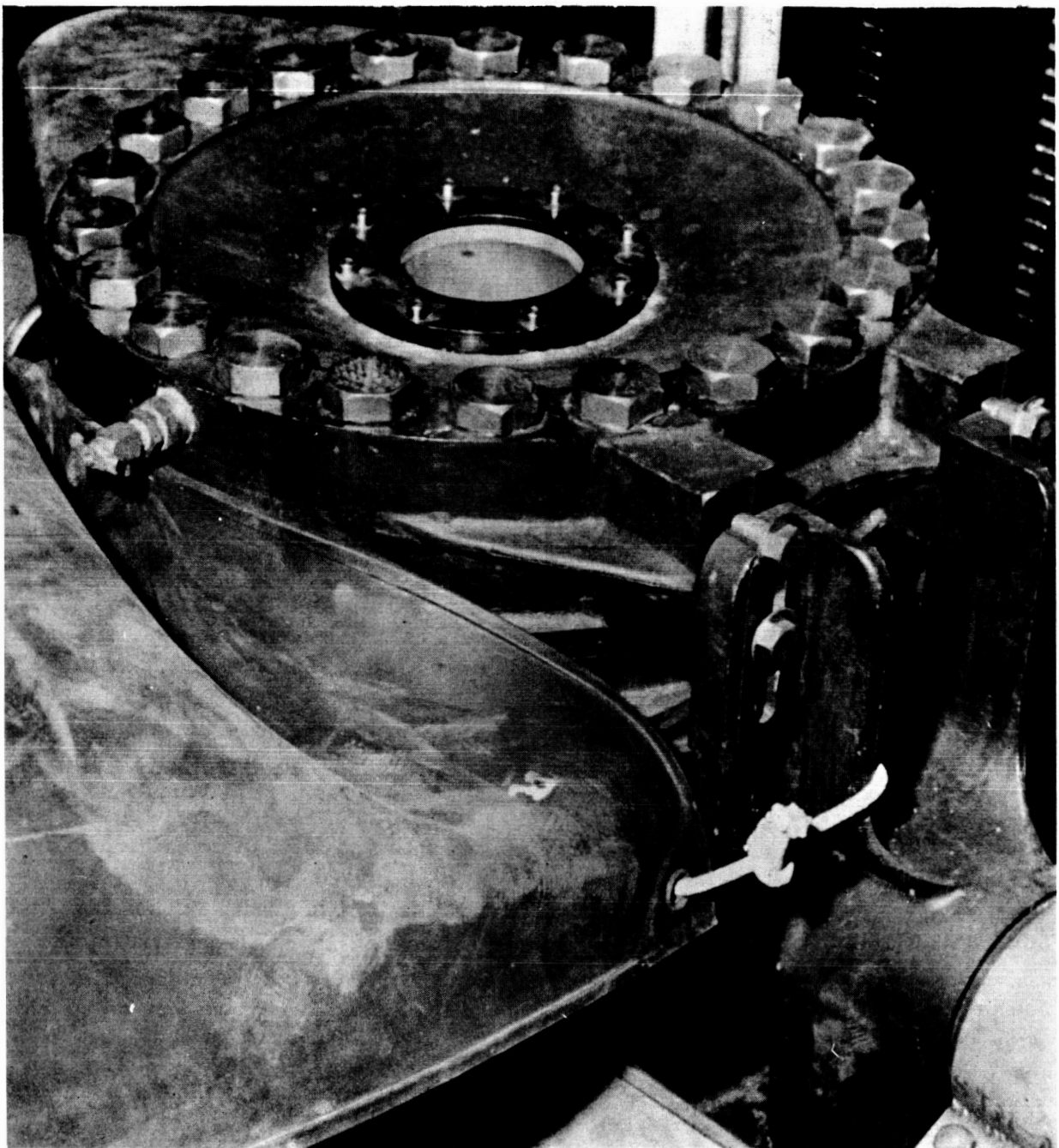


Figure 1

Top view of a Bitter magnet with 4-inch core at the National Magnet Laboratory,  
Massachusetts Institute of Technology, Cambridge, Massachusetts

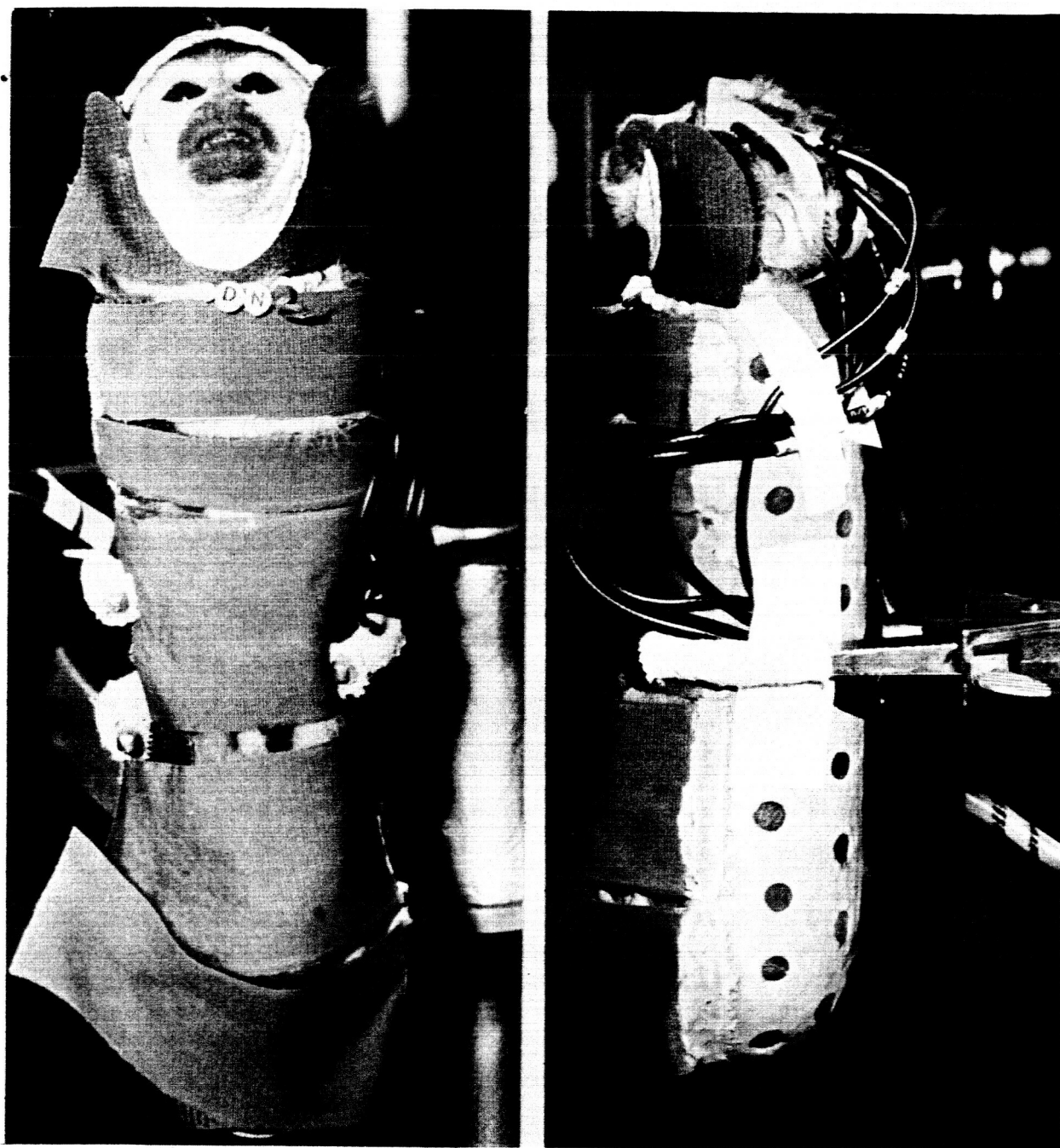


Figure 2

Front and side view of a restrained squirrel monkey (Saimiri sciureus)  
with inserted scalp electrodes

For insertion into the magnet the cylinder containing the animal was lowered into the core to a preselected position which either placed its head in the center of the magnet with the strongest homogeneous field or at various distances above or below the center in a gradient field of lesser intensity. Figure 3 illustrates the relationship of the animal's position and field strength during the second series of experiments at the Naval Research Laboratory. In the first series at NRL the maximal field strength was 72,450 oersted. The last series of experiments conducted at NML used fields as high as 91,250 oersted. The field of the NRL magnet was increased and decreased at a rate of 500 - 1,000 oersted per second, and the NML magnet's rate was approximately 6,000 oersted per second. Both magnets provided automatically regulated constant fields.

Regulation of the environmental temperature for the animal in the magnet presented some problems. The temperature in the core changed with the load and varied along the length of the core, with the highest temperature at the ends where the current is conducted to the magnet. At NRL during the first experiments a plastic cylinder with abundant air flow created suitable ambient conditions for the monkeys, as indicated by normal rectal temperature readings. For the second series at NRL a copper-metal water-jacket maintained the ambient air around the animal at  $26^{\circ} \pm 1^{\circ} \text{C}$ . Rectal temperature measurements of these animals were also normal during the entire experiments. At NML a plastic water-jacket kept the ambient air at  $24.8^{\circ} \pm 0.2^{\circ} \text{C}$ .

The following schedules of exposure of monkeys to very high magnetic fields were chosen:

#### SERIES I (NRL) (2 animals)

1. 30-minute baseline (magnet not activated).
2. Homogeneous field, normal polarity (north pole at bottom of magnet, south pole at top), in stepwise fashion from 0 to 40,000 oersted, to 72,450 oersted, remaining at each step for 45 minutes during which time EEG recordings were taken.
3. Corresponding stepwise decrease to magnet power cut-off.
4. Baseline.

#### SERIES II (NRL) (5 animals)

1. 15-minute baseline (magnet not activated).
2. Homogeneous field, normal polarity (north pole at bottom of magnet, south pole at top), in stepwise fashion from 0 to 20,000 oersted, to 40,000 oersted, and to 60,000 oersted, remaining at each step for 3 minutes with EEG recordings.

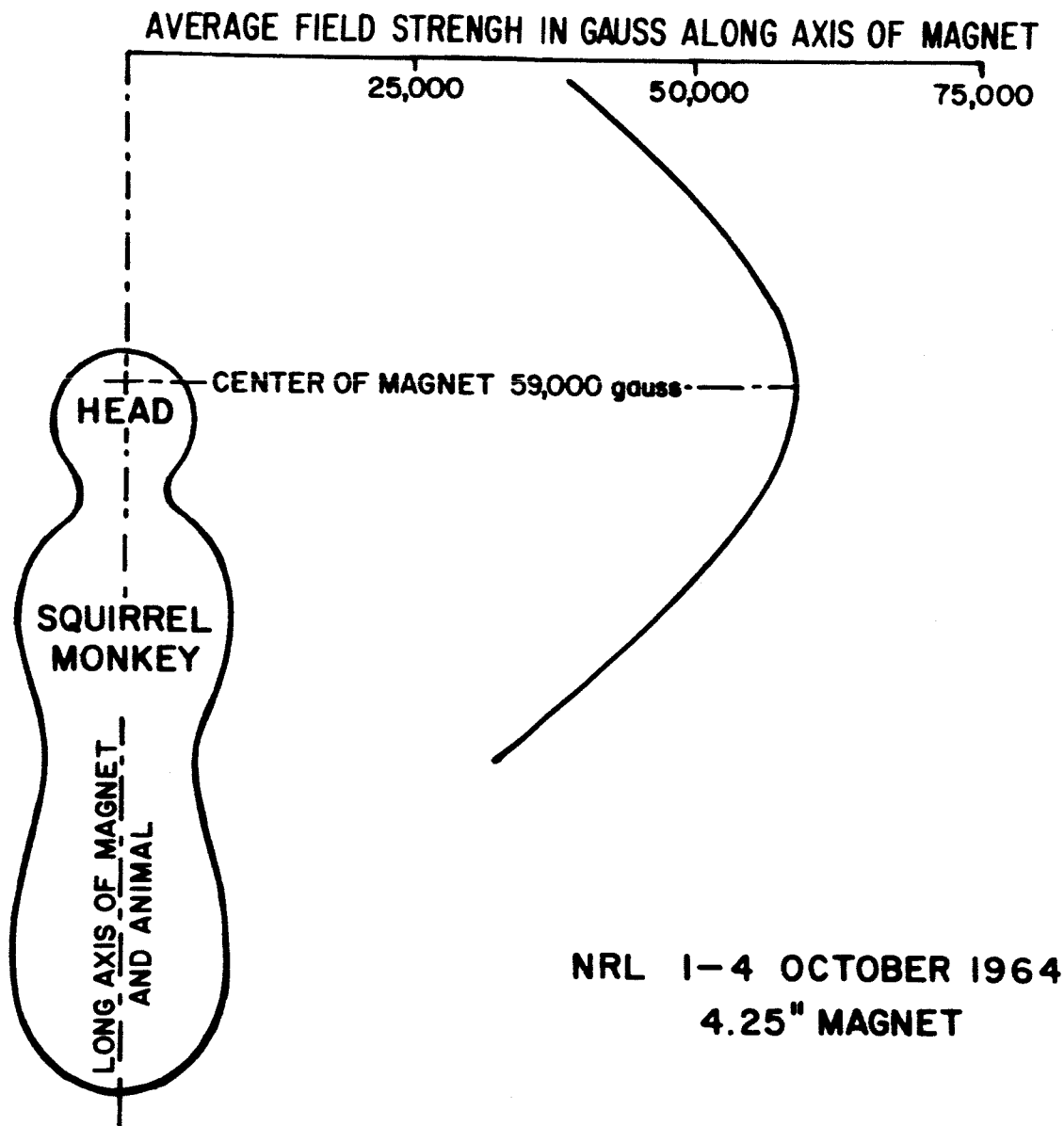


Figure 3

Relationship of a squirrel monkey's brain position to the field distribution of the 4-inch magnet at the U. S. Naval Research Laboratory, Washington, D. C.

3. Corresponding stepwise decrease to magnet power cut-off.
4. Reverse polarity of magnet and repeat 2 and 3.
5. Gradient field, normal polarity and repeat 2 and 3.
6. Gradient field, reverse polarity to 44,000 oersted and decrease to power cut-off, recording EEG continuously.
7. Baseline.

#### SERIES III (NML) (2 animals)

1. 10-minute baseline (magnet not activated).
2. Gradient field, normal polarity, in stepwise fashion from 0 to 22,540 oersted, to 45,472 oersted, to 68,414 oersted, to 91,258 oersted, remaining at each step for 1 minute with EEG recordings.
3. Corresponding stepwise decrease to magnet power cut-off.
4. Baseline.

### EEG EVALUATION AND RESULTS

Visual examination of the single-channel electroencephalograms taken during the Series I experiments suggested a possible influence of the magnetic field. Subsequent Series II experiments were conducted using the same magnet, but deriving 6 bipolar channels of EEG recordings from five left-side electrodes. This set of experiments was analyzed by measuring each cycle within varying lengths of the continuous spontaneous EEG at different stages of the experimental protocol. Also, continuous three-minute spontaneous recordings were computer-analyzed (Mnemotron CAT Model 400B) for presence of repetitive signals of the EEG at different field strengths. Typical findings using these analytical methods are given for two different animals in Figures 4 and 5. The EEG's of three of the second series monkeys recorded during power-off and power-on conditions of the magnet are illustrated in Figures 6 and 7. It was observed that the prevailing frequencies of the squirrel monkey in the power-off phase were from 8 to 12 cps, with a peak-to-peak amplitude of 25 to 50 microvolts. During the power-on phase the majority of the frequencies were higher than 12 cps, usually between 14 and 50 cps, and with an amplitude of 50-400 microvolts. No differences in the EEG's were recorded while the monkeys were exposed to homogeneous and to gradient fields nor could any influences of polarity changes be found.

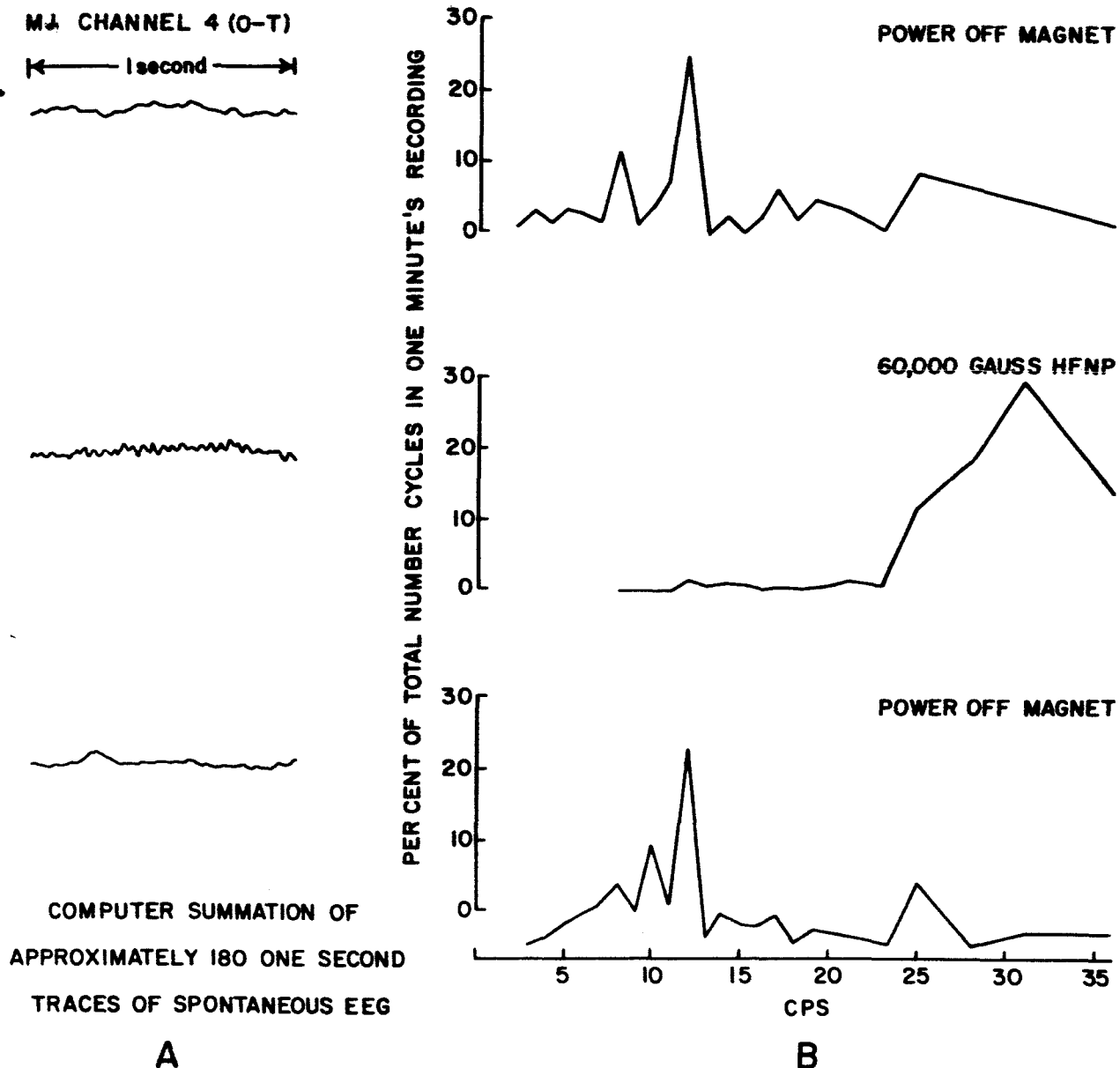


Figure 4

Typical results from two analytical methods utilized for evaluation of the spontaneous electroencephalograms of squirrel monkey "MJ": (A) CAT computer summation of about 180 serial one-second EEG records before, during, and after magnetic field exposures; (B) Graphs derived from measurement of each successive cycle in one-minute EEG's before, during, and after magnetic field exposures.

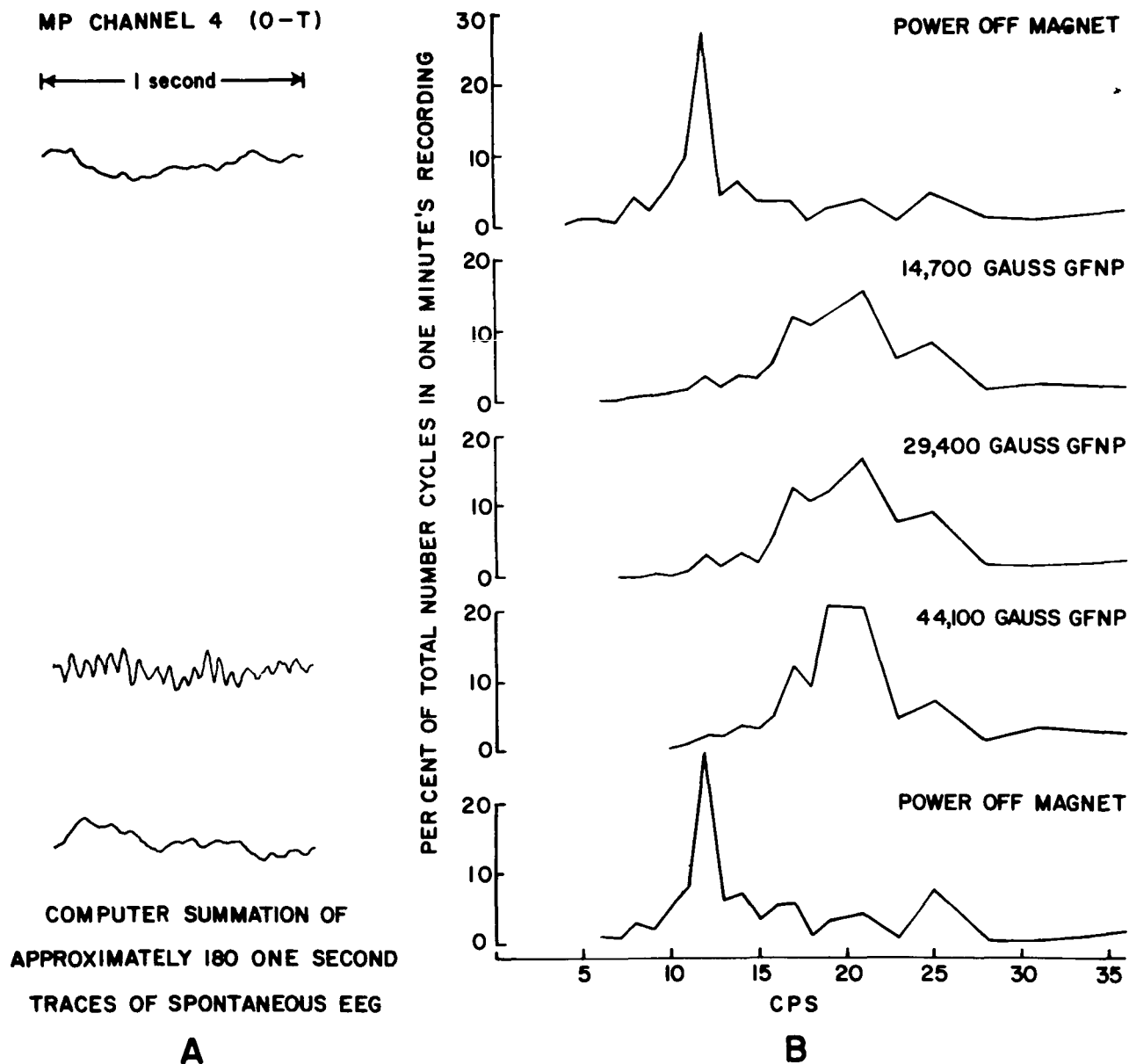


Figure 5

Typical results from two analytical methods utilized for evaluation of the spontaneous electroencephalograms of squirrel monkey "MP": (A) CAT computer summation of about 180 serial one-second EEG records before, during, and after magnetic field exposures; (B) Graphs derived from measurement of each successive cycle in one-minute EEG's before, during, and after magnetic field exposures.

LI HFNP 10/3/64

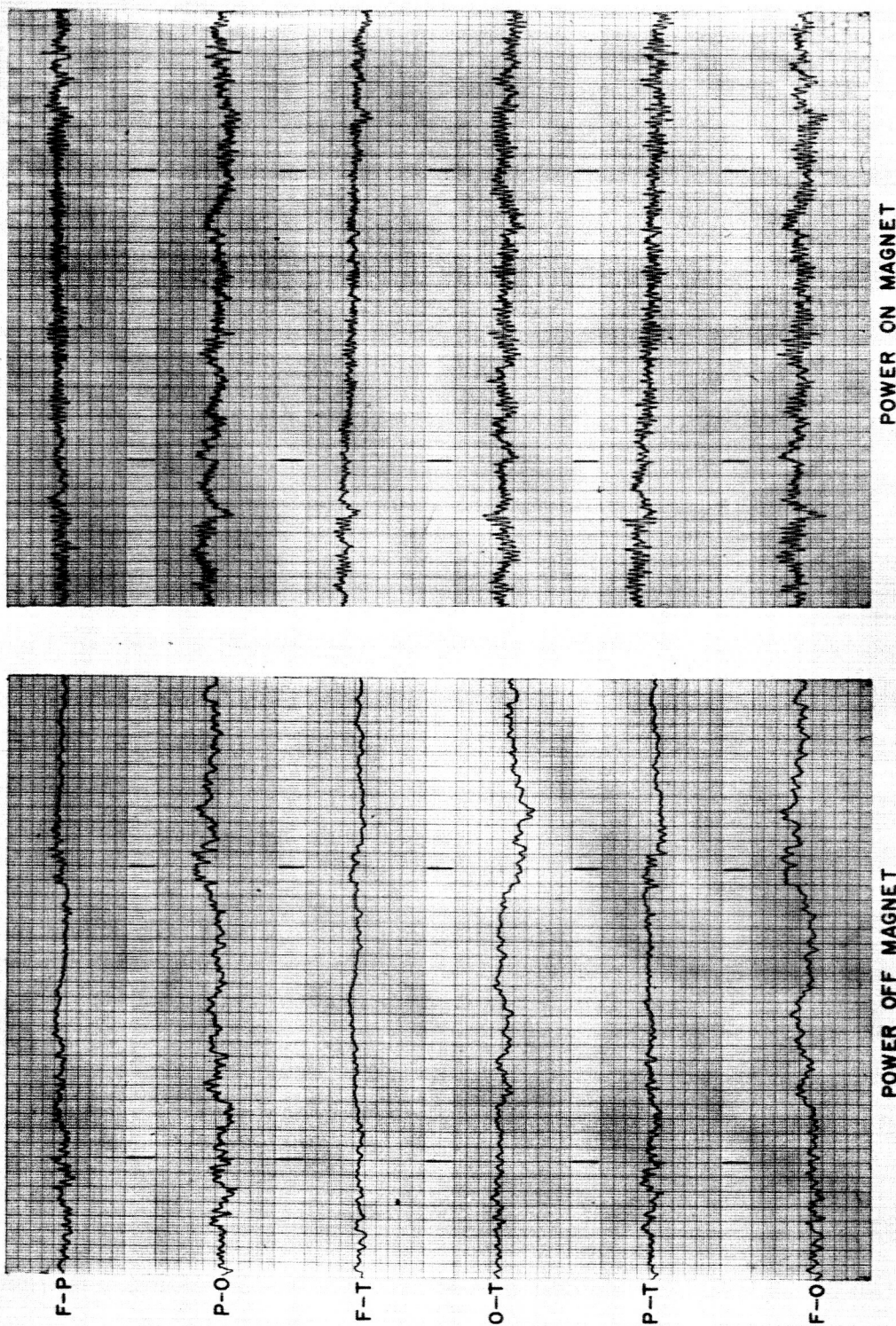


Figure 6

Representative traces of electroencephalograms derived from left scalp electrodes (F, frontal; P, parietal; O, occipital; T, temporal) of squirrel monkey "LI." Field conditions of NRL magnet at head of animal: Homogeneous field 60,000 oersted, normal polarity (NP = south pole at top of magnet).

MP GFNP 10/2/64

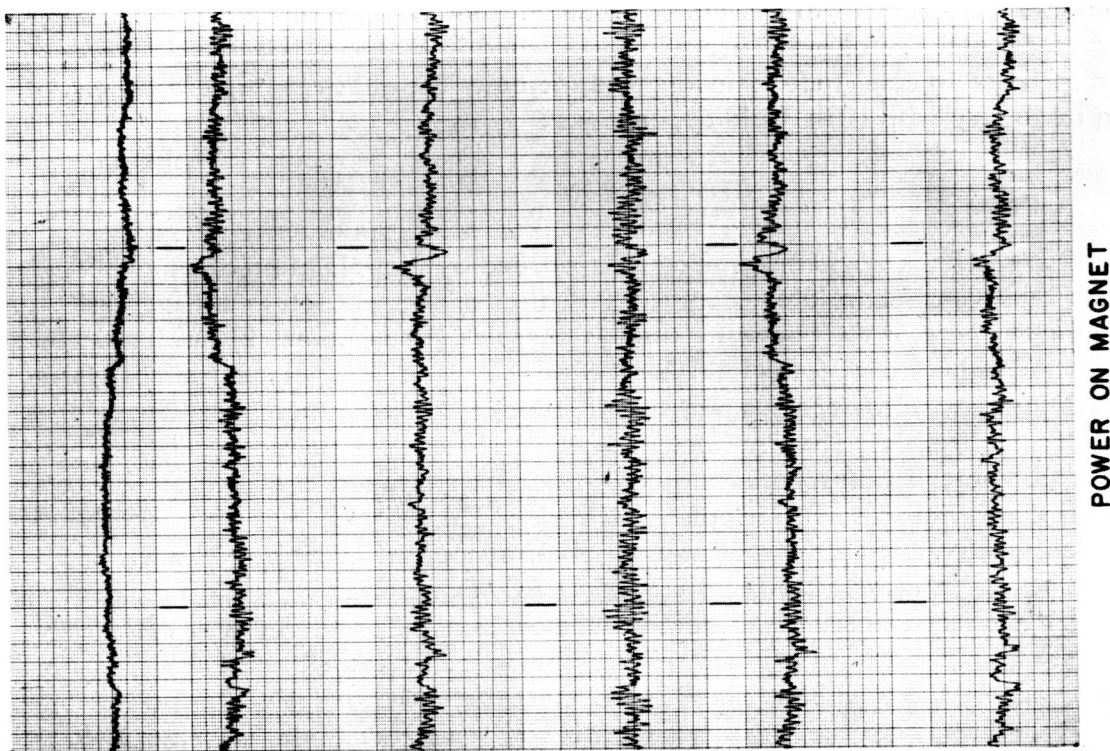
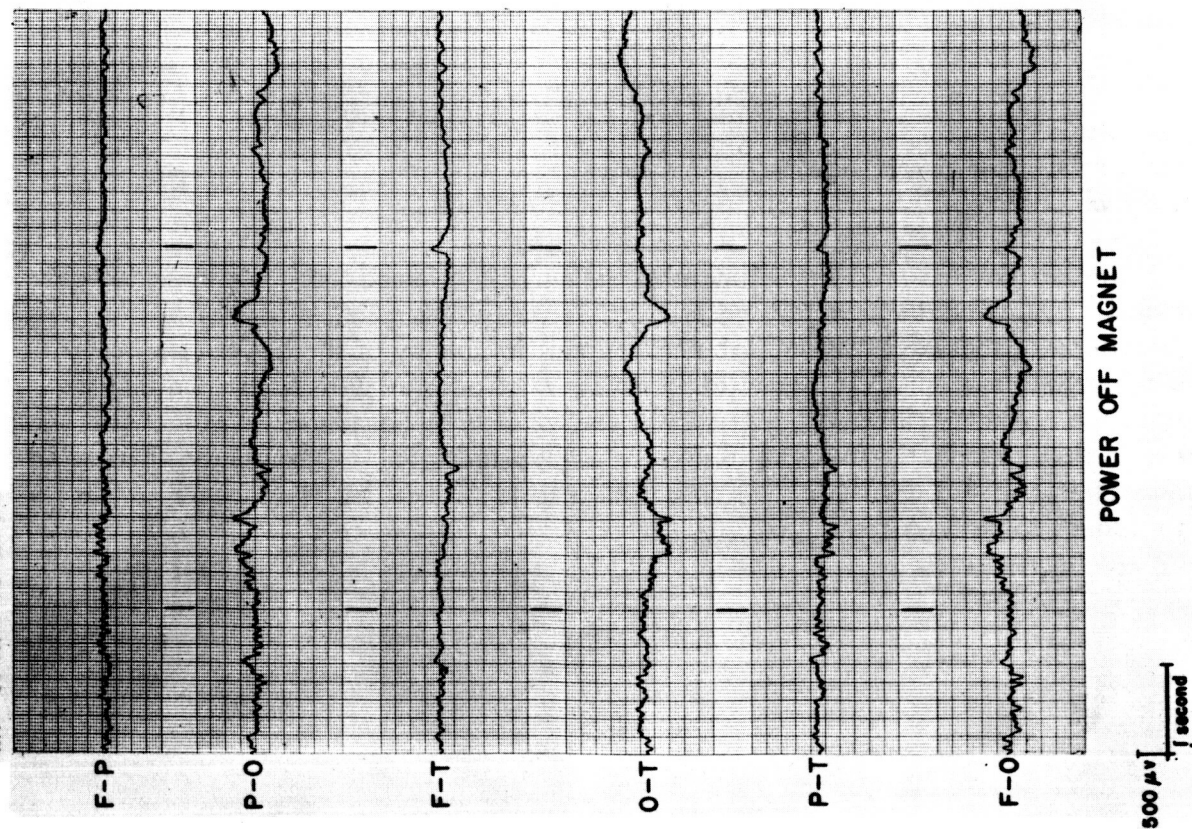


Figure 7

Representative traces of electroencephalograms derived from left scalp electrodes of squirrel monkey "MP." Field conditions of NRL magnet at head of animal: Gradient field with 2,500 oersted gradient at 44,100 oersted, normal polarity.

Figure 8 is representative of the EEG's obtained from the two monkeys exposed at NML and demonstrates the characteristic features found in high magnetic field recordings: 1) an increase in amplitude following the increase in field strength, and 2) an increase in frequency with little field dependence.

## DISCUSSION

Artifacts in the EEG measurement may be produced by the induction of a signal in the EEG loop by several nonrelated sources. Potential origins of such an artifact are: 1) the ripple component of the generator used to energize the magnet, 2) involuntary movements of the animal connected with heart rate and breathing, 3) mechanical vibration of the magnet caused by cooling water, 4) 50-cycle interference, and 5) skeletal muscle tonicity and tremor. The first four sources of artifact may be reasonably excluded because their characteristic frequencies are outside the spectrum of predominant frequencies of the measured tracings. The ripple frequency of the NML magnet of 6, 12, and 85 cps was well below and above the predominant electroencephalographic frequency of the animal in the magnetic field. Respiratory rate (1 cps), heart rate (3-5 cps), and mechanical vibration (4 cps) were lower than the 14-50 cps EEG range, and the 60 cps line frequency was higher. This leaves muscle tremor as a possible source of artifact. The recordings in Figure 8 show a tracing which is similar to the EMG of skeletal muscle with abnormal tonus. The possibility of this artifact cannot be excluded before subcranially implanted electrodes have replaced scalp electrodes and results have been evaluated.

The EEG registered in the magnetic field did not reveal any signals constant in frequency and amplitude as might be expected from some of the above sources of artifact but did show current oscillations which changed randomly in amplitude and frequency, the characteristic waxing and waning of an EEG. Furthermore, differences of signal strengths and frequencies in the leads were observed, indicating absence of extrinsic induction which would influence all leads to a similar extent.

If artifacts can be considered eliminated, it may be inferred that strong magnetic fields exert a significant synchronizing effect on brain waves as demonstrated by the high amplitude of the waves. The high predominant frequency of the EEG of squirrel monkeys in strong magnetic fields would normally be associated with activation and tension of the animal. However, preliminary results of behavioral studies of squirrel monkeys in strong magnetic fields, which will be reported later, demonstrated decreasing performance in a visual discrimination task. At a field strength of 90,000 oersted the animals ceased to perform their task.

A56 3/24/66

F-P

P-O

F-T

O-T

P-T

F-O

POWER OFF MAGNET

POWER ON MAGNET

500  $\mu$ V  
1 second

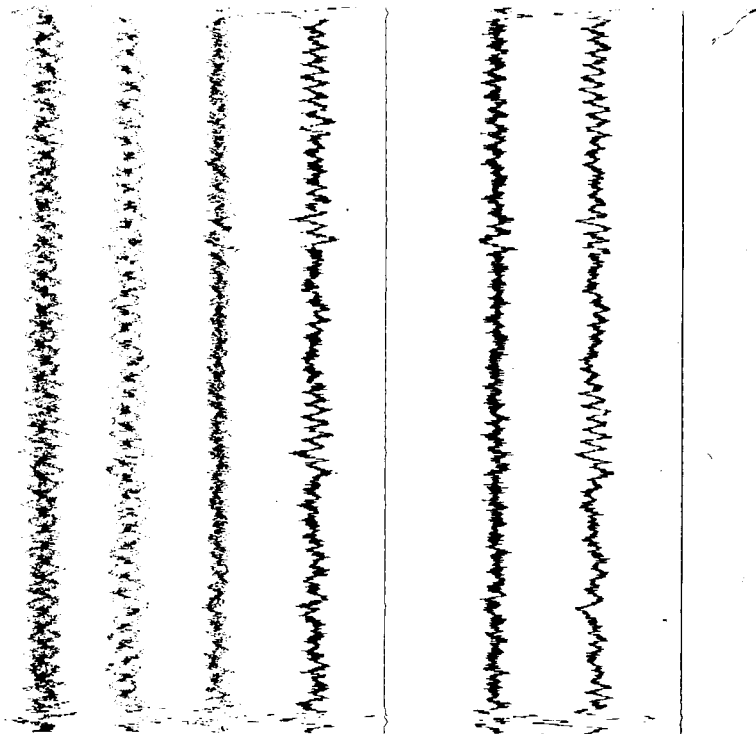


Figure 8

Characteristic traces of electroencephalograms derived from left scalp electrodes of squirrel monkey "A56." Field conditions of NML magnet at head of animal: Gradient field with 3,260 oersted gradient at 91,250 oersted.

Kholodov (3,4) has found that the character of the reaction to a magnetic field depended on the initial functional state of the central nervous system. In his experiments using encephale isole of rabbits in a static magnetic field of about 800 oersted the EEG showed a highly significant increase in the number of spindles in the frontal region of the cerebral cortex, as well as an increase in the number of slow high-amplitude oscillations in the occipital region. Under the action of the magnetic field the EEG of rabbits (it is assumed intact animals were used) exhibited acute (beta) waves which reflected a process of excitation. He further states that although a magnetic field produced an inhibitory state, it may also provoke excitation in the central nervous system. Observations of Becker (5) on a tranquilized amphibian in a magnetic field of 3,400 oersted showed diminution of alpha waves and the appearance of delta waves in the EEG. The waveform in the magnetic field is characterized by Becker as typical for moderate to deep surgical anesthesia of the animal.

Judging from all these observations it appears that strong magnetic fields have a significant effect on the central nervous system and that this effect is predominantly manifested as deactivation. However, the high frequencies in the EEG of squirrel monkeys in strong fields do not fit into this general picture and are either due to an artifact or represent a sequence of rapid discharges which disrupt the coordinated functioning of the central nervous system.

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Electroencephalogram (EEG)						
Oersted						
Squirrel monkey						
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